

# Earth Observing 1 (EO-1) Decommission Overview

## Mission Operation Working Group (MOWG)

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6/14/2017





# Mission Overview



# Mission Overview

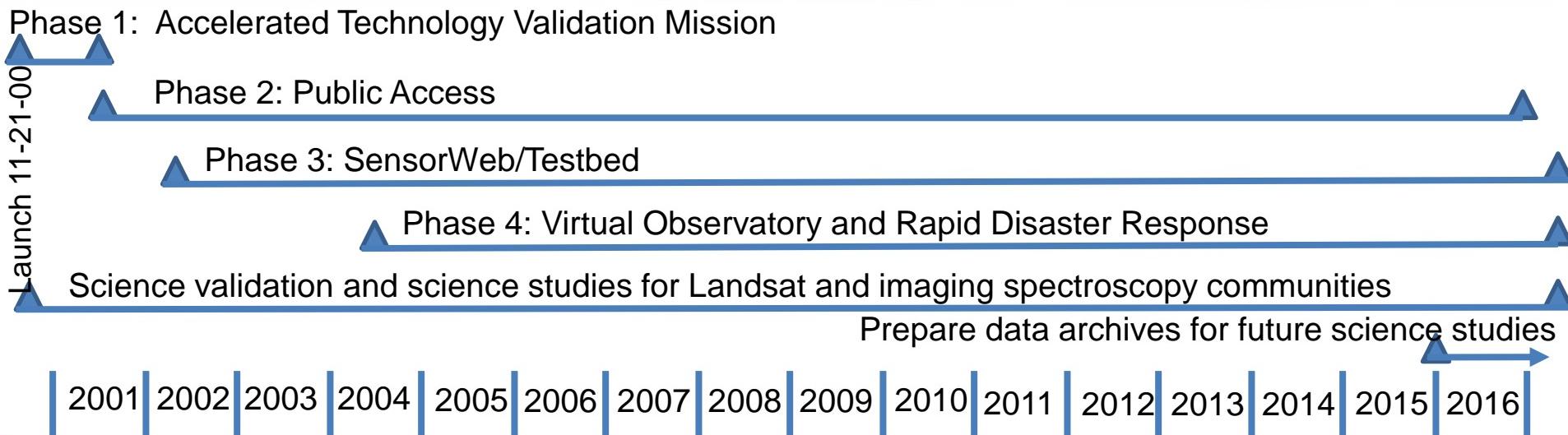


- EO-1 originated as a technology validation mission and pathfinder next generation Landsat and other missions
- Launched November 21, 2000 on a one year mission from Vandenberg into a sun-synchronous circular low earth orbit at 705km altitude one minute behind Landsat-7
- Required to collect 200 paired images with Landsat-7

*Details about the mission, instruments, science, applications, and technologies are contained on the EO-1 mission website at <https://eo1.gsfc.nasa.gov/>*



# Mission Overview



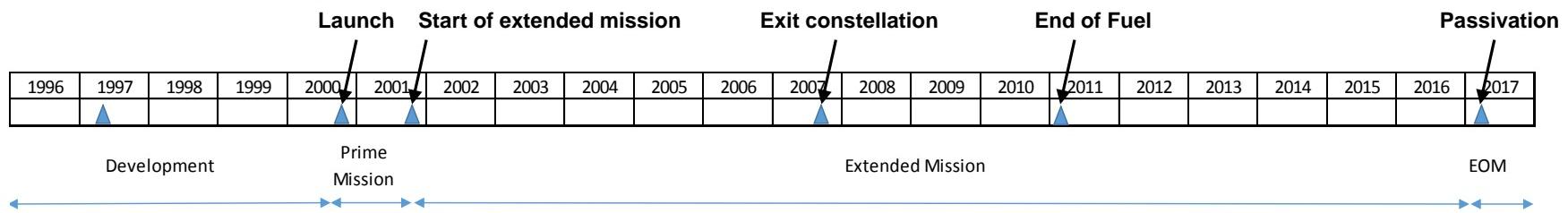
- EO-1 was originated as a space technology validation mission to act as a pathfinder for next generation Landsat and other missions
- Phase 1 was designed to validate the original 13 technologies in a shortened timeframe
- Phase 2 was designed to provide a wide distribution of the key instrument data which extended to the end of the mission
- Phase 3 added various onboard and ground software to validate inter-sensor collaboration techniques and to provide a space validation testbed
- Phase 4 added various software technology to improve mission efficiency and demonstrate various aspects of virtualizing the user interface to EO-1



# EO-1 Mission Overview and Status - Background



- EO-1 was launched November 21, 2000 as a 1-year Technology Validation mission into a sun-synchronous circular low earth orbit in formation one minute behind Landsat-7
- EO-1 completed the validation of all 13 baseline technologies on schedule; including, the Advanced Land Imager (ALI) precursor to the Landsat Operational Land Imager (OLI) and the Hyperion instrument precursor to the Hyperspectral Infrared Imager (HyspIRI) mission.
- EO-1 was extended for further on-orbit spacecraft technology validation and land imagery science data capture and distribution.
- EO-1 instruments are healthy. The spacecraft has experienced a GPS issue, a recorder management limitation, and some battery cell shorts that are all being operationally mitigated.
- EO-1 exhausted its fuel for orbit maintenance in 2011, and as a result the orbit has been decaying in altitude and drifting in mean local time.
- 2013 and 2015 Senior Review panels have concluded that by 2016 the orbit geometry will provide limited science value





# Mission Overview: Instruments



- Advanced Land Imager (ALI) – push-broom multi-spectral with 9 spectral bands (30m per pixel resolution) and one panchromatic band (10m resolution)
  - Precursor to the Operational Land Imager on-board Landsat-8



- Hyperion hyper-spectral with over 200 spectral bands operating in the range from 400 – 2400 nm (10nm bandwidths for each of the over 200 bands)
  - Precursor to the instrument planned for the HyspIRI mission



- Linear Etalon Imaging Spectral Array (LEISA) Atmospheric Corrector
  - Precursor to the instrument on-board the New Horizons mission

# Some stats



**Time EO-1 in operations:  
Nov 21, 2000 to March 30, 2017  
= 5973 days**

**#orbits in operations = 87205  
(that is orbit # that we turned off)**

**EO-1 mass at launch 570.5 kg**  
**- TRMM 3524 kg**  
**- Terra 4863 kg**

**#Hyperion and Ali images:  
–over 92000 each**

**# Archived documents est: 4000-5000**  
**# pages archived est: 100000-200000**  
**Still working on this!**

**#papers & conference presentations:  
1805 (have index)**

**#people who worked on EO-1: 560**

## More stats

Received many external technology awards post launch related to extension of EO-1 Operations

#Flight Operation Team Leads: 7

- Alicia Kost
- Joe Howard
- Robert Bode
- Seth Shulman
- Baran Sahin
- Russell Dehart
- Ben Holt

# years I have been on EO-1  
as of June 2017: 20

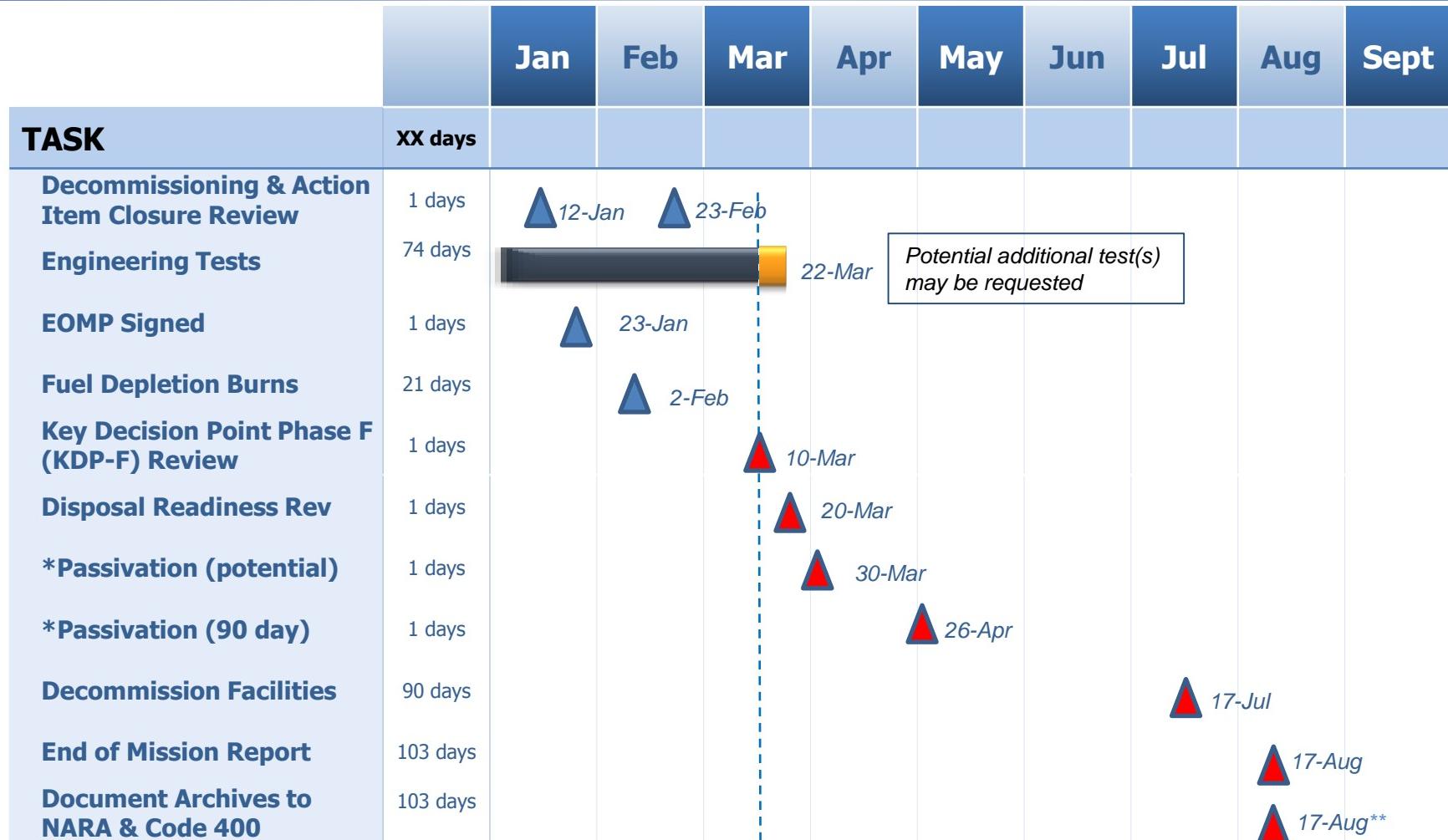




# Decommission Overview



# Top Level 2017 Decommissioning Schedule



**\*Dependencies:**

1. Passivation on March 30 or as directed by HQ
2. Delivery of document archives to NARA depends on resolving issue of NARA capable of receiving electronic records.

\*\* delay possible to move items to NARA



▲ completed

▲ Not started

Competed      Portion to be completed



# EO-1 Engineering Tests



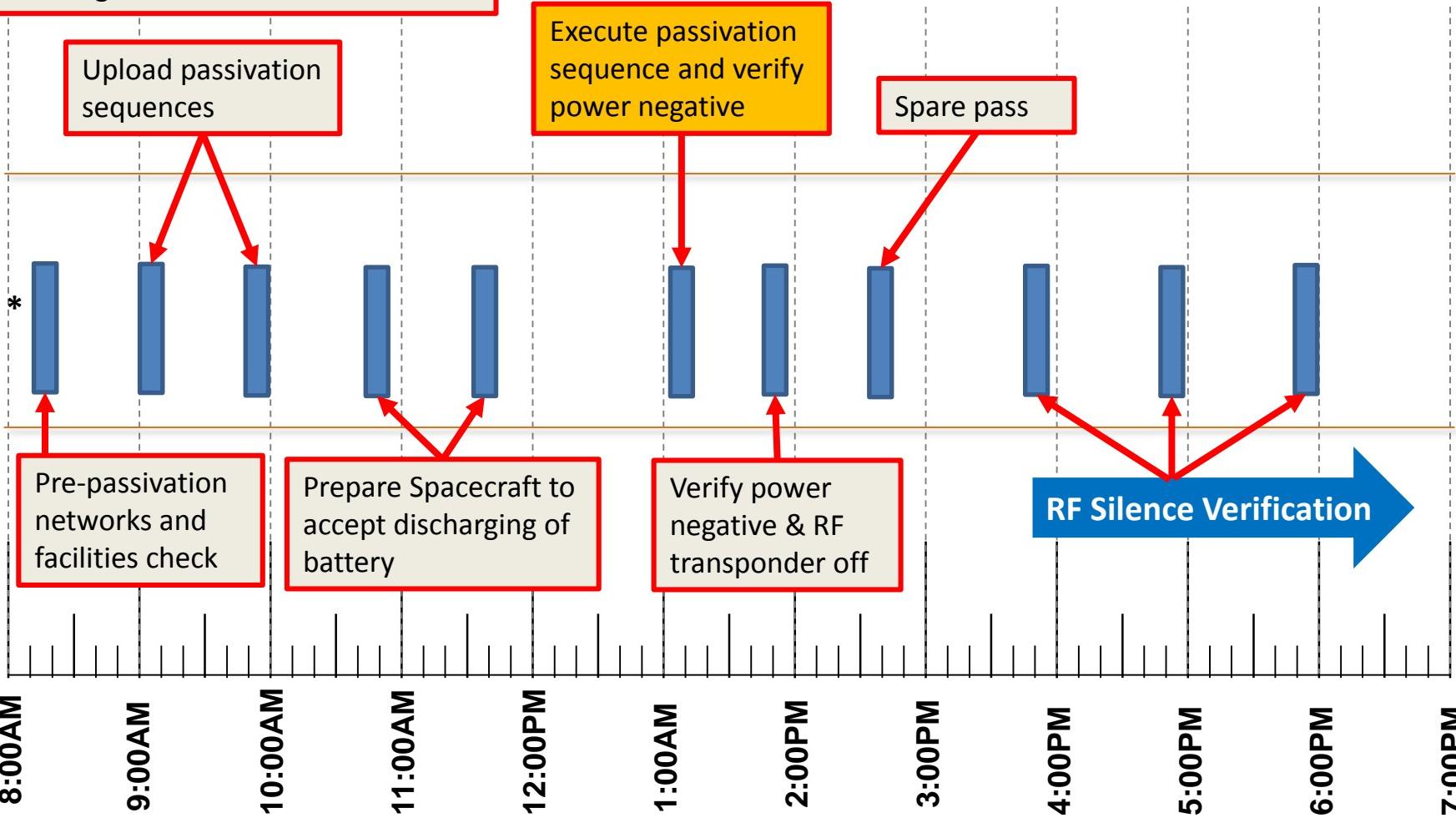
<b><i>Test</i></b>	<b><i>Description</i></b>	<b><i>Status</i></b>
Pulse Plasma Thruster	Final tests of one of the original EO-1 technologies to test if firing Teflon ablation PPT contaminates imaging ability of Hyperion instrument.	2 tests were successfully completed.
Min/Max Drag Test	Validate model which predicts orbital displacement by increasing and decreasing the drag area and demonstrate operational implementation.	Conducted multiple tests.



# Passivation Day Activities Schedule



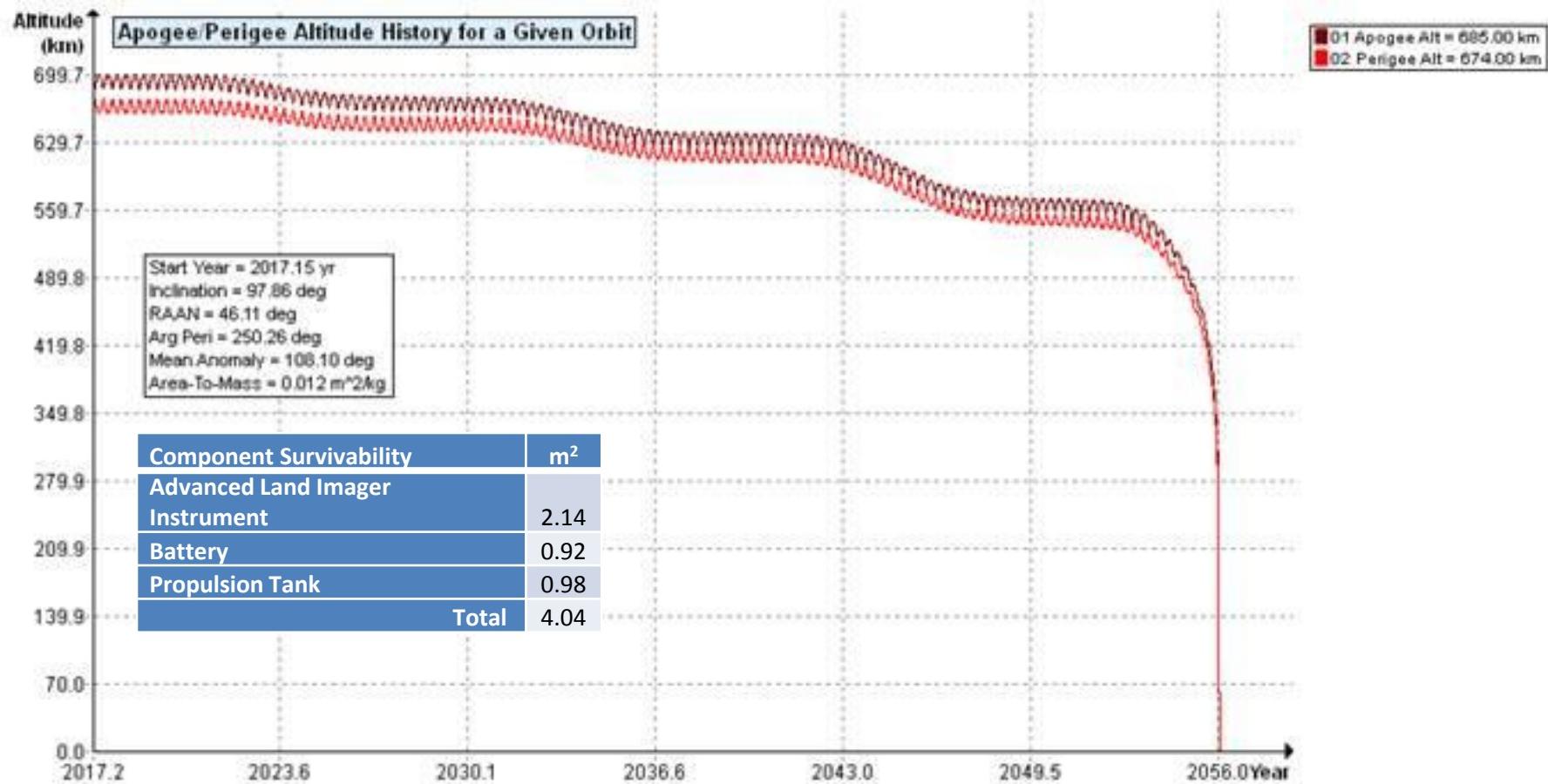
- ✓ Check that critical personnel present
- ✓ Verify Pre-Passivation Checklist
- ✓ Check state of spacecraft
- ✓ Briefing



\* The actual GN/TDRS pass times will be available 2-weeks prior to passivation date.



# EO-1 Reentry Profile



- An uncontrolled reentry is predicted to occur in approximately 2056
  - requirement: reenter within 25 years of passivation, not compliant with predicted re-entry in 39 years, waiver approved
- Spacecraft Debris Casualty Area (DCA) is 4.04 m<sup>2</sup>
- Probability of human casualty from reentering debris of about 1 in 19,400
  - Requirement 1 in 10,000 compliant



# End of Mission Requirements/Constraints



Reqm't #	Compliant or N/A	Not Compliant	Incomplete	Comments from EOMP by Section Number
4.3-1.a	x			DEBRIS RELEASE - No debris is released by the spacecraft bus or instruments during normal operations or disposal.
4.3-1.b	x			OBJECT-TIME PRODUCT - N/A
4.3-2	x			GEO-SYNCHRONOUS EARTH ORBIT (GEO) LIFETIME - N/A
4.4-1	x			ACCIDENTAL EXPLOSION - The probability of explosion for EO-1 of less than 0.001 cannot be demonstrated quantitatively, but the intent of the requirement is met.
4.4-2		x		<b>DEPLETION OF STORED ENERGY</b> - Sections 4.2 and 6.6 list actions to be taken to passivate the spacecraft, however compliance of all components cannot be achieved due to the Power and Propulsion system designs. <a href="#">Waiver granted</a> .
4.4-3	x			INTENTIONAL BREAKUP - N/A
4.4-4	x			INTENTIONAL BREAKUP - N/A
4.5-1	x			LARGE OBJECT COLLISION - Section 5.2 assesses that the subject probability is less than the 0.001 requirement and thus is compliant based on the remaining number of years on orbit.
4.5-2		x		<b>SMALL OBJECT COLLISION</b> - Section 5.3 assesses that the subject probability is greater than the 0.01 requirement. <a href="#">Waiver granted</a> .
4.6-1(a)		x		<b>25 YEAR REENTRY</b> – Re-entry 39 years after passivation. <a href="#">Waiver request has been granted (OD-07-15)</a> .
4.6-1(b)	x			ON-ORBIT STORAGE - N/A
4.6-1(c)	x			DIRECT RETRIEVAL - N/A
4.6-2	x			DISPOSAL NEAR GEO - N/A
4.6-3	x			DISPOSAL BETWEEN LOW EARTH ORBIT (LEO) AND GEO - N/A
4.6-4	x			DISPOSAL RELIABILITY - Section 6.7 assesses the subject probability of success to be at least 0.90.
4.7-1	x			<b>CASUALTY RISK</b> - Section 7.2 assesses the reentry risk to be 1:19,400, which is compliant with the requirement of 1:10,000.
4.8-1	x			TETHERED SYSTEM - N/A



# Archives and Documents

- USGS will maintain long-term archive of EO-1 Science and Housekeeping Data (data already archived at USGS)
- GSFC Flight Projects Library will maintain repository of technical and administrative records (Progressing as planned)
- National Archives and Records Administration (NARA) will maintain archive of historically-significant information (Issue transferring Records to NARA)
  - EO-1 electronic records are being categorized and labeled according to the NASA Records Retention Schedules (NRRS 1441.1A)
  - TRMM electronic records also followed NRRS, however were not accepted by NARA
    - NARA rejected transfer request either due to over-simplification of record description submitted or due to a change in NARA requirements that is not accurately captured in NRRS.
    - The GSFC Center Records Manager (Peggy Jenkins) is seeking a path to records acceptance by NARA, with support from the GSFC FPD Records Manager (Nancy Rosenbaum)
  - Awaiting resolution between NASA and NARA on acceptable descriptions for the large accessions of records before being able to proceed
- Spacecraft Operations Final Report (Progressing as planned)
  - Details the spacecraft mission from a high-level operations status
  - Includes references to other forms of operations reports to support future mission inquiries
  - Includes Lessons Learned



# Budget and Schedule Impacts

- EO-1 is operated with a small team with a small budget
  - 3 person Flight Ops Team with ~\$2.8M per year budget including operations and science
- Large anomalies were not planned for in the PPBE
- In 2016, EO-1 experienced multiple anomalies
  - Battery Cell Anomaly (03/23/2016) – resulted in Safe Hold
  - GPS Anomaly – Anomaly discovered during restart of GPS during Safe Hold recovery on 03/29/2016. Onboard incorrect GPS week number issue.
    - Significant effort by team to attempt recovery
    - Investigated code changes to compensate
    - Developed, tested and implemented manual process to manage spacecraft clock and uplink spacecraft ephemeris
  - Battery Cell anomaly (07/22/2016) – resulted in Safe Hold
- Archive effort was larger than anticipated
- The above anomaly investigation and recovery efforts, plus the requirements for archiving the documentation exceeded available budget



# Rehearsals



- Conducted 4 formal rehearsals
  - Two Nominal passivations to verify that prime and backup personnel could support passivation
  - Contingency passivation
  - Dress rehearsal



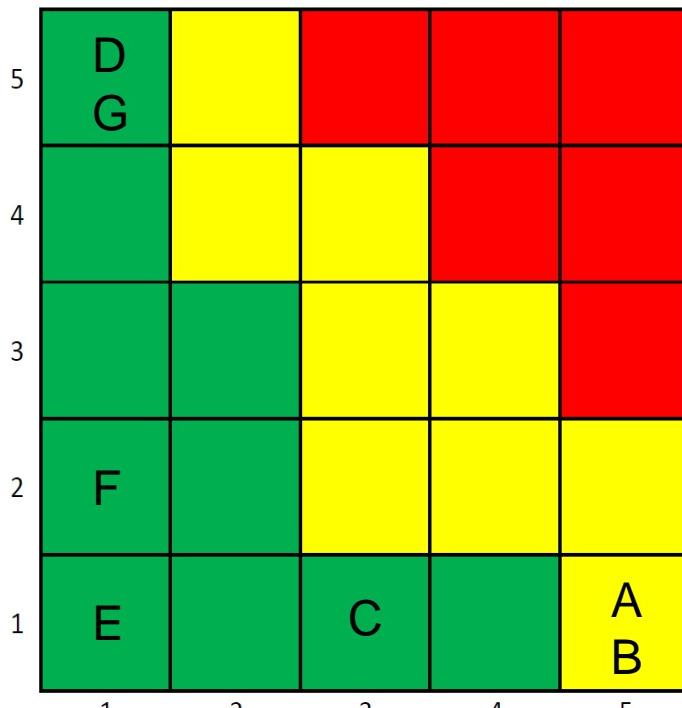
# Turning EO-1 Off on March 30, 2017





# Decommissioning Risk Matrix

Likelihood



ID	Trend	Approach	Risk Title
A	➡	A	CA Risk after Fuel Depletion
B	➡	A	On-board Anomaly
C	⬇	M	Passivation Readiness
D	⬆	M	Delay of Passivation Execution (Budget impact - Realized)
E	⬇	M	Staffing (end of contract)
F	■	M / A	Schedule Risk
G	■	M	Records Archive

Criticality	LxC	Trend	Approach
High	⬇	Decreasing (Improving)	M - Mitigate
Med	⬆	Increasing (Worsening)	W - Watch
Low	➡	Unchanged	A - Accept
	■	New Since Last Period	R - Research

	1 Very Low	2 Low	3 Moderate	4 High	5 Very High
Likelihood	0.1% < P <sub>T</sub> < 2%	2% < P <sub>T</sub> < 15%	15% < P <sub>T</sub> < 25%	25% < P <sub>T</sub> < 50%	P <sub>T</sub> < 50%
Consequence	No impact to full Passivation at expected Dates & completion of all objectives	Minor impact to full Passivation & completion of all objectives	Moderate impact to full Passivation & completion of all objectives. Minimum Passivation & completion of all objectives achievable with margin	Major impact to full Passivation & completion of all objectives. Minimum Passivation & completion of all objectives achievable	Minimum Passivation & completion of all objectives is not achievable.



# Decommissioning Risks (cont'd)



Rank	ID	Risk Statement	Approach	Status
<b>Conjunction Risk between now and passivation (1 × 5)</b>  <span style="background-color: yellow; border: 1px solid black; padding: 2px;">Y</span>	A	<p><b>If</b> CARA identifies a probable conjunction prior to passivation</p> <p><b>Then</b> EO1 may not be able to perform an adequate Debris Avoidance Maneuver and possibly be hit hindering Passivation</p>	Accept	<ul style="list-style-type: none"><li>Accept that EO-1 will not be able to execute a Risk Mitigation Maneuver</li></ul>
<b>On-board Anomaly occurs before passivation (1 × 5)</b>  <span style="background-color: yellow; border: 1px solid black; padding: 2px;">Y</span>	B	<p><b>If</b> On-board Anomaly occurs within a component critical to passivation</p> <p><b>Then</b> full passivation may not be completed</p>	Accept	<ul style="list-style-type: none"><li>All components necessary for passivation are fully functional as of this review</li></ul>
<b>Passivation Readiness (1 × 3)</b>  <span style="background-color: green; border: 1px solid black; padding: 2px;">G</span>	C	<p><b>If</b> Passivation preparations are inadequate</p> <p><b>Then</b> passivation may not be successful</p>	Mitigate	<ul style="list-style-type: none"><li>Passivation products including stored commands, procedures, and new pages have been baseline and tested against the simulator</li><li>Passivation day script has been developed to include contingency SOPs and pre-passivation checklist with waive-off criteria</li><li>Passivation rehearsals are were conducted to prepare team. All personnel (prime and backup) required for passivation have been certified</li></ul>



# Decommissioning Risks (cont'd)



Rank	ID	Risk Statement	Approach	Status
<b>Delay of Passivation Execution</b> <i>(5 × 1)</i>  <span style="background-color: green; color: white; padding: 2px 5px;">G</span>	D	<p><b>If</b> passivation execution is delayed beyond February 23, 2017</p> <p><b>Then</b> EO-1 budget will be insufficient to support end of mission activities.</p>	<b>Mitigate / Closed</b> <u>(Realized)</u>	<ul style="list-style-type: none"><li>Met with HQ on this issue Friday January 27, 2017</li><li>Passivation date moved to March 30, 2017</li><li><b>Mission requires ~\$217K additional budget to complete Phase F based on new passivation date.</b></li></ul>
<b>Staffing (end of ops contract)</b> <i>(1 × 1)</i>  <span style="background-color: green; color: white; padding: 2px 5px;">G</span>	E	<p><b>If</b> the existing staff is not available for executing the passivation due to a contract changeover</p> <p><b>Then</b> Passivation will have to be performed by operators who are unfamiliar with peculiarities of EO-1 and may not be successful in accomplishing passivation</p>	<b>Mitigate</b>	<ul style="list-style-type: none"><li>Worked with contract team to ensure that we retain a contract vehicle to maintain staff in place through end of decommissioning</li><li>Current Contract goes through May 2017 due to protest of follow-on contract.<ul style="list-style-type: none"><li>If protest is upheld, will remain with current contract</li><li>If protest is withdrawn or overturned, can either remain with current contract or transition to new contract since same company will provide service</li></ul></li></ul>
<b>Schedule Risk</b> <i>(2 × 1)</i>  <span style="background-color: green; color: white; padding: 2px 5px;">G</span>	F	<p><b>If</b> key milestones are not achieved</p> <p><b>Then</b> passivation date may slip</p>	<b>Mitigate / Accept</b>	<ul style="list-style-type: none"><li>Closed all 18 Decommissioning Review RFA's by February 23, 2017</li><li>KDP-F scheduled for March 10, 2017</li><li>Awaiting HQ approval for early passivation required before March 22, 2017</li></ul>



# Decommissioning Risks (cont'd)



Rank	ID	Risk Statement	Approach	Status
<b>Record Management Archive (5 x 1)</b>  <span style="background-color: green; color: black; padding: 2px 5px;">G</span>	G	<p><b>If</b> unable to establish National Archives and Records Administration (NARA) agreement on electronic file archives as encountered with TRMM Archives</p> <p><b>Then</b> final archive may be delayed beyond EO-1 closeout</p>	<b>Mitigate</b>	<ul style="list-style-type: none"><li>Working with GSFC Center Records Manager, the GSFC Archivist, and the GSFC FPD Records Manager, seeking language clarification requirements and a path to records acceptance by NARA.</li><li>Allocated additional staff while personnel are available.</li><li>Plan to allocated additional funds to assist ESMO beyond EO-1 Closeout if archive is not complete</li></ul>



# ESMO Project Issue Summary



Status as of 1/31/2017

## Records Management – Archive Issues

	Problem/Issue	Impact/Concern	Action	Status
Y	National Archives and Records Administration (NARA) has rejected multiple submissions of the TRMM electronic archives based on the requirement for specific meta data for each file on each type of media (CDs and hard drives).  TRMM hardcopy records have already been accepted by NARA.	The 17 years of TRMM electronic records will not go into archives as part of the final decommissioning step of the mission.  Completion of EO-1 decommissioning in Spring of 2017 could be significantly delayed due to issues with archiving electronic records.	<ol style="list-style-type: none"><li>1. Work with the GSFC Center Records Manager to negotiate the NARA requirements for electronic records.</li><li>2. Disposition the 6 remaining boxes of TRMM electronic media records</li><li>3. Ensure that EO-1 records can be expeditiously archived during decommissioning.</li></ol>	<ol style="list-style-type: none"><li>1. <u>Waiting for feedback from the Center Records Manager on the required input to the NARA submission forms.</u> ESMO is drafting recommendations for consideration in future NPR / GPR versions.</li><li>2. ESMO investigating the effort required to prepare the meta data for the thousands of files in the electronic archives</li><li>3. ESMO is compiling the EO-1 archives list and assessing the impact of meeting the NARA requirements.</li></ol>



# Other Lessons Learned



- More effort and coordination than originally anticipated, especially due to the fact that there was no good way to disable the power
- We had no good way to do spacecraft simulations because that was not part of the original design of the mission.
  - Original design did not take into account turning off the satellite or how it would be done.
  - Lack of high fidelity simulator
  - Original budget did not take into account all of the system engineering, testing and rehearsals
- Added end of mission engineering tests which also was not part of the original budget (did streamline operations and made it work)



# Decommission Documentation



# Phase F Documentation Products (7120.5E)



	Reqt Source, 7120.5, Appendix I	Reqt Owner		Where
Mishap Preparedness & Contingency Plan	I-4, HQ Products, #6	OSMA		not required for extended missions
End of Mission Plan	I-4, Project Technical Products, #14	OSMA	Complete	EOMP
Baseline Phase F Work Plan	I-4, Project Mgt, Planning & Control, #3	OCE	Complete	Project Phase F Plan
Documentation of Performance against last approved baseline	I-4, Project Mgt, Planning & Control, #4	OCE	Complete	Presentation
Phase F Risk Assessment	I-4, Project Mgt, Planning & Control, #5a	OCE	Complete	Project Phase F Plan
Phase F Cost Estimate	I-4, Project Mgt, Planning & Control, #5e	OCE	Complete	Project Phase F Plan
Basis of Estimate for Phase F cost & schedule	I-4, Project Mgt, Planning & Control, #5f	OCE	Complete	Project Phase F Plan
CADRe	I-4, Project Mgt, Planning & Control, #5i	CAD	In Work to include Phase F costs	
Decommissioning Plan	I-4, Project Mgt, Planning & Control, #6	OCE	Complete	Project Phase F Plan
Safety & Mission Assurance Plan	I-5, #2	OSMA	not required for extended missions	
Security Plan	I-5, #17	OPS	Updated annually	ESMO System Security Plan
Project Protection Plan	I-5, #18	OCE	N/A	
Communications Plan		OComm	Complete	Presentation
Termination Notification Letter	NPR 8010	SMD	Complete	ESD Correspondence Files

Table I-4: Project Milestone Products Maturity Matrix  
Table I-5: Project Plan Control Plans Maturity Matrix



# End of Mission Plan (EOMP)



EO-1 EOMP  
Effective Date: October 3, 2016  
Expiration Date: October 3, 2017

Document Revision	Approval Date	Description
Baseline	January 2008	Initial Release, Incomplete approvals
Revision 1	July 2012	Updated to reflect NASA-STD 8719.14A requirements, current spacecraft status, and full approvals
Revision 2 (Final)	October 2016	Final version to reflect current spacecraft and orbit status and EOM plan implementation. Includes updated decommissioning requirements gleaned from the Phase F report dated 17 June 2016. Also Includes added detail about the passivation sequence. Over 50% of text was changed since the June 2012 version, so a whole new version of the document is being submitted instead of redlines.

428- PLAN-005, Revision 2  
Earth Science Mission Operations Project Code 428

**Earth Observing- 1 (EO-1) Satellite  
End of Mission Plan (EOMP)  
Final Version**



National Aeronautics and  
Space Administration

Goddard Space Flight  
Center  
Greenbelt, Maryland

Check the ESDB/ESNO/EO-1 Doc Server at <https://gsfc-near.gsfc.nasa.gov/EO-1/> to verify that this is the current version prior to use



# EOMP Addendum Memo



Document Revision	Approval Date	Description
Fuel Purge Addendum	March 2017	<p>Table 2-2 item on Propulsion System amended as described below.</p> <p>Section 4.2 on Accidental Explosions amended as described below.</p> <p>Section 6.6 Passivation, list item 6 amended as described below</p>

Logic: Agreement was reached with Orbital Debris Program Office (ODPO) and Office of Safety and Mission Assurance (OSMA) that when EO-1 could not complete a 100 second burn without an autonomous Attitude Control Subsystem (ACS) abort due to “sputtering” of the thrusters, that would demonstrate sufficient exhaustion of the fuel tank. Experts agree that EO-1 is essentially out of fuel since the subsequent maneuver performed on February 2, 2017 terminated after only 60 seconds because there was insufficient fuel to maintain attitude control. Any attempts to further deplete the fuel will result in entering Safe Hold as there is insufficient fuel to control the spacecraft.

Also, after submitting the EOMP to Configuration Management, it was determined that the EO-1 propulsion design prohibits leaving thruster valves open for extended durations. Leaving thruster valves open indefinitely is not possible without significant effort to obviate the onboard design.

EO 1 EOMP  
Effective Date: October 3, 2016  
Expiration Date: October 3, 2017

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**428-PLAN-005, Revision 2**  
**Earth Science Mission Operations Project Code 428**

**Earth Observing-1 (EO-1) Satellite**  
**End of Mission Plan (EOMP)**  
**Final Version with Fuel Purge Addendum**



**NASA**  
National Aeronautics and Space Administration

Goddard Space Flight Center  
Greenbelt, Maryland

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# Decommissioning Documentation



- Orbital Debris Assessment Report performed in 1999 (copy included in the EOMP)
  - An uncontrolled reentry is predicted to occur in approximately 2056
  - The EOMP states that the calculated spacecraft Debris Casualty Area (DCA) is  $4.04 \text{ m}^2$ , which adjusted for the expected population density for its orbit at the time of reentry, produces a probability of human casualty from reentering debris of about 1 in 19,400, which is compliant with requirement 4.7-1 (1:10,000).
  - It should be noted that only 69% of the spacecraft mass was included in the original DAS assessment that had been completed prior to launch and information on the components that had been omitted from the original DAS assessment is not available to do a complete assessment now